SPECIAL REPORT 97-28

Current and Proposed Practices for Nondestructive Highway Pavement Testing

Maureen A. Kestler

November 1997

Abstract: In September 1994 the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) distributed a short survey on nondestructive testing practices to each of the 50 state Departments of Transportation (DOTs). The compilation of results constituted Phase I of a multiphase effort intended to lead toward the development of a method for optimizing falling weight deflectometer (FWD) test point spacing. Planned spatial statistical analyses on selected data sets will yield (site-specific) optimal FWD test point spacing for road network evaluation and pavement overlay design. Optimal FWD test point spacing reduces conservative overdesign due to undertesting and reduces overtesting. Both of these ultimately reduce expenditures. Although the above effort has not been completed, this interim report outlines the proposed process. Also included (and perhaps of more immediate interest to state DOTs) are direct survey facts and figures, including number of states with nondestructive testing (NDT) devices, average number of miles of annual overlay design, average number of miles of network/inventory testing, and backcalculation programs and overlay design procedures used. All facts and figures are generic and honor state anonymity.

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PREFACE

This report was prepared by Maureen A. Kestler, Research Civil Engineer, Civil Engineering Research Division, Research and Engineering Directorate, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire.

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Current and Proposed Practices for Nondestructive Highway Pavement Testing

MAUREEN A. KESTLER

OVERVIEW

In September 1994 the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) distributed a short survey on nondestructive testing practices to each of the 50 state Departments of Transportation (DOTs). The following report briefly summarizes state responses to questions regarding nondestructive testing (NDT) equipment used or owned, number of lane-miles tested annually, software and analytical tools utilized, and NDT test point spacing and configuration.

Compilation of survey results constituted Phase I of a multiphase effort leading toward development of a method for optimizing falling weight deflectometer (FWD) test point spacing. Long-range objectives are to assess national expenditures on NDT and to work in cooperation with selected state DOTs to determine whether present costs for overlay design and pavement evaluation could be reduced by the development of a computer program that continually assesses and updates in-situ variability, and recommends an optimal distance to the next FWD test point as data are collected in the field. This interim report* includes neither an analysis nor a final product, but rather summarizes survey results and outlines the theory and planned approach for computer program development.

SURVEY RESULTS

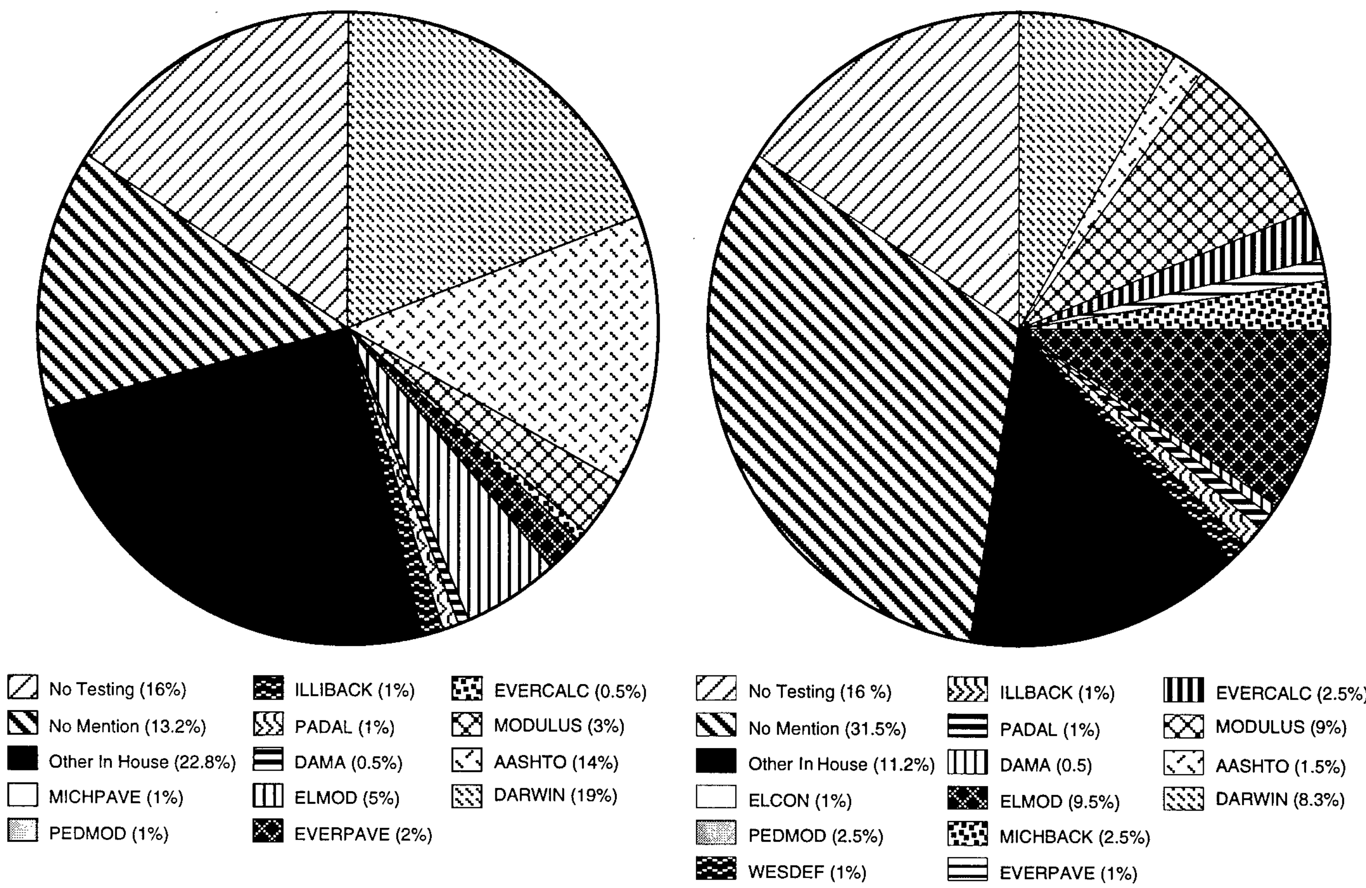
NDT equipment

The NDT Practices Survey was distributed to the 50 state DOTs during the fall of 1994. Thirty-eight states replied, indicating a response rate of 76%. Of the 38 responding states, 21 states own (Dynatest) FWDs. Further investigation (Dynatest 1993) beyond survey results showed that, as of November 1993, six of the nonresponding states also owned Dynatest FWDs. Two states contract FWD work, six states own KUABs, one state owns a Mechanics Foundation JILS, three states own Road Raters, and four states continue to use Dynaflects. Several states own combinations of the above devices, e.g., one state owns two Dynatest FWDs and one KUAB, another state owns one Dynatest FWD and two Dynaflects, etc. Each of the NDT devices reported in this survey are briefly discussed in Appendix A (Smith and Lytton 1984).

NDT equipment uses and software/analytical tools used

Predominant uses for NDT equipment are pavement overlay design, pavement evaluation, network/inventory, research, void detection, and load transfer for portland cement concrete (PCC) pavements. Table 1 summarizes NDT software and analytical tools most commonly used by state DOTs. Figures 1a and 1b graphically show the breakdown in methods/software for overlay design, evaluation, network, and project level usage. American Association of State Highway and Transportation Officials (AASHTO) guidelines and DARWIN, a computer-aided design method that uses AASHTO methods, provide the most frequently used overlay design technique of those reported. "In-house overlay design programs," ranging from sophisticated internally developed software to more simplistic spreadsheets, are also often used. (Note that weighted averages were assigned for figure development, i.e., states using only one software program were assigned a weight of one whereas states that specified three overlay design methods were assigned three weights of 1/3 each.)

*This report was written in response to numerous requests for a copy of the paper associated with a presentation titled "What Do DOTs Do with FWDs?", given at the FWD User's Group Meeting in Raleigh, North Carolina, in October 1995.



a. Software (overlay).

b. Software (network and project level).

Figure 1. Breakdown of software used.

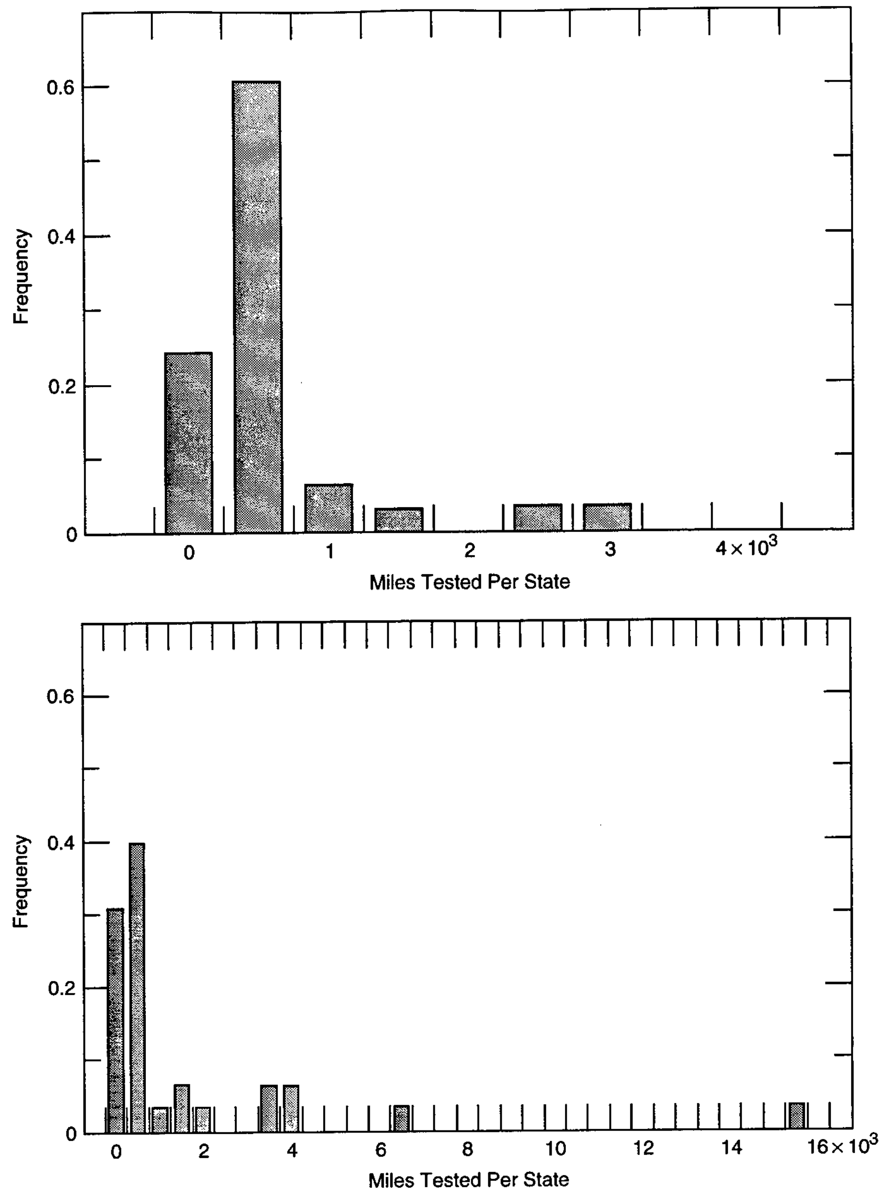
Table 1. Nondestructive testing software and analytical tools used by state DOTs.

	Evaluation/ network	*Overlay design*
DARWIN	X	X
AASHTO	X	X
MODULUS	X	X
EVERCALC	X	X
ELMOD	X	X
EVERPAVE	X	X
WESDEF	X	X
PADAL	X	X
ILLIBACK	X	X
ELCON	X	X
PEDMOD	X	X
DAMA	X	X
MICHBACK	X	
MICHPAVE		X
Other in-house programs	X	X

Generally, FWDs are being used by state DOTs more for overlay design than for other purposes. However, DARWIN (and AASHTO), MODULUS, and ELMOD are the most commonly used methods for evaluation. Again, no individual in-house program is used across the board; nevertheless, a large percentage of states use their own software.

Miles tested

Figures 2a and 2b show the distribution of lane-miles tested per state both for overlay design and at the network level, respectively. With a few exceptions, most states test fewer than 700 lane-miles per year for overlay design. Figure 2b shows that the vast majority of states test fewer than 1000 lane-miles per year at the network level. Note that these histograms indicate miles per state, not miles per piece of DOT equipment; thus, Figure



a. Overlay design.

b. Network level.

Figure 2. Miles tested per state.

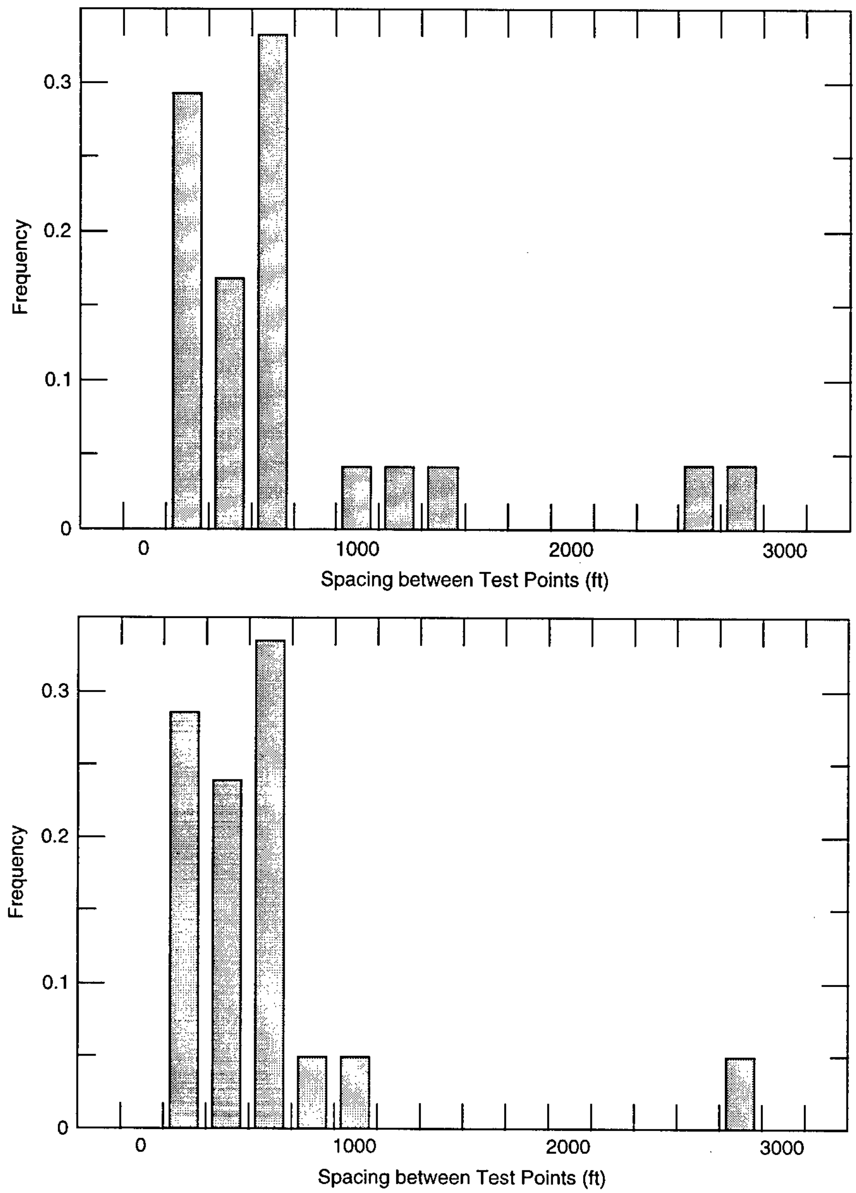
2b's outlier of approximately 15,000 miles per year corresponds to a state with an entire fleet of FWDs.

Spacing and configuration of NDT test points

Survey results indicated somewhat of a correlation between test pattern and "new and old" FWD owners. Generally, new owners test in multiple locations (e.g., centerlines and wheelpaths) whereas veteran owners, for the most part, tend to test in just the right wheelpath. Spacing for purposes of network/inventory and overlay design tends to range from 100 to 1000 ft (Fig. 3a and 3b). Outlier reports of spacing for both purposes approach 3000 ft. Spacing could not always be quantified as a particular distance because several states indicated a minimum number of test points per project.

PLANS FOR OPTIMIZING TEST POINT SPACING

Pavement design and evaluation models and testing equipment continue to grow increasingly sophisticated, but only a limited amount of attention has been directed toward answering questions regarding the optimal number and location



a. Overlay design.

b. Network level.

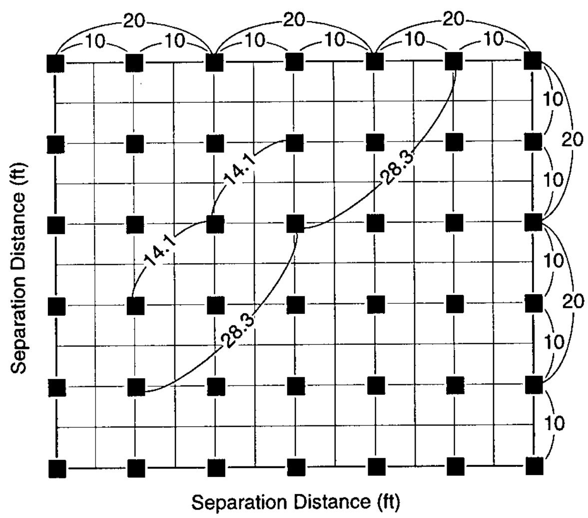
Figure 3. Distance between NDT test points.

of FWD test points. Following completion of pavement strength variability analysis, we hope to minimize the cost for overlay design and pavement evaluation by developing a computer program to optimize the number and location of FWD test points. Ideally, it would continually adjust the optimal distance to the next test point in real time as data are collected in the field. Based upon preliminary work, this continually adjusting optimal test point configuration computer program would maximize efficiency of FWD testing by 1) eliminating both undertesting and overtesting (thereby eliminating underdesign and overdesign), 2) minimizing lane closure time (thereby improving both employee and public safety), and 3) guaranteeing that adequate data are collected for overlay design and pavement evaluation.

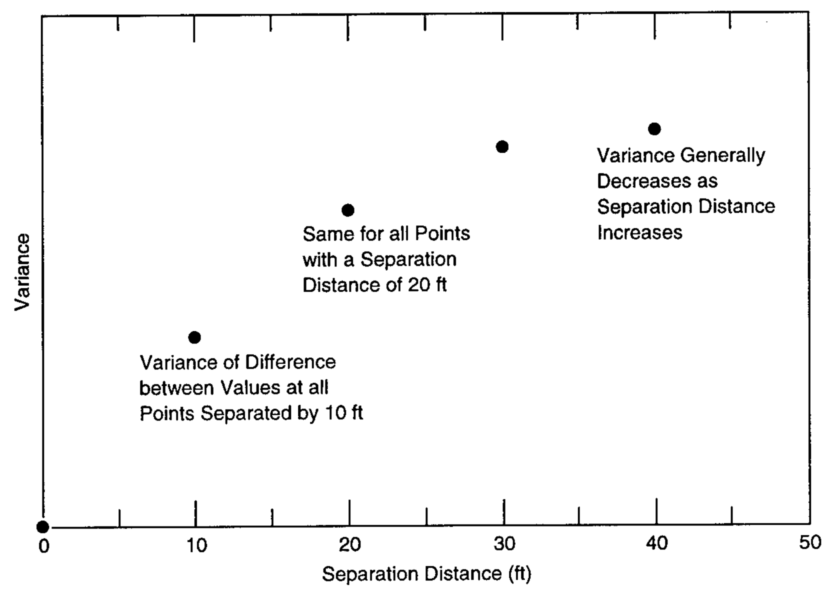
Classical statistics can address random variability, but neglects relative positions of test points. However, there currently exist several less traditional mathematical models that can quantify spatial variability of pavement properties.

The following is a simplified look at a geostatistical model that provides the basis for the proposed test point spacing optimization program.

Test points located close together (e.g., the 10-ft grid in Fig. 4a) yield similar test values. The variance (or statistical measure of spread) of differ-



a. Sample test grid.



b. Variogram development.

Figure 4. Test grid and associated variogram development.

ences between test values at pairs of test points separated by such a small distance will be minimal. This can be repeated for larger separation distances. For this particular test grid, the next closest spacing is 14.1 ft. The variance continues to increase up to a certain separation distance at which it levels out as shown in a geostatistical semivariogram (Fig. 4b). This is the distance beyond which the values (in this case, modulus or deflection) are no longer auto-correlated. Figure 5 shows the variogram corresponding to FWD data at a test cell at the Minnesota Road Research Program (Mn/ROAD) (Kestler et al. 1994). Points closer than approximately 150 ft are correlated; those spaced farther than 150 ft are independent of each other. While the variogram should define test point separation distances as outlined here, this analysis should remain invisible to the typical user.

There are currently many geostatistical software packages both available for purchase and in the public domain. They all analyze data at one point in time. We plan to modify an existing shareware package to continually update the optimal distance to the next FWD test point, as the data are collected, based on all previous data collected on that pavement during that test session. As pavement strength variability increases,

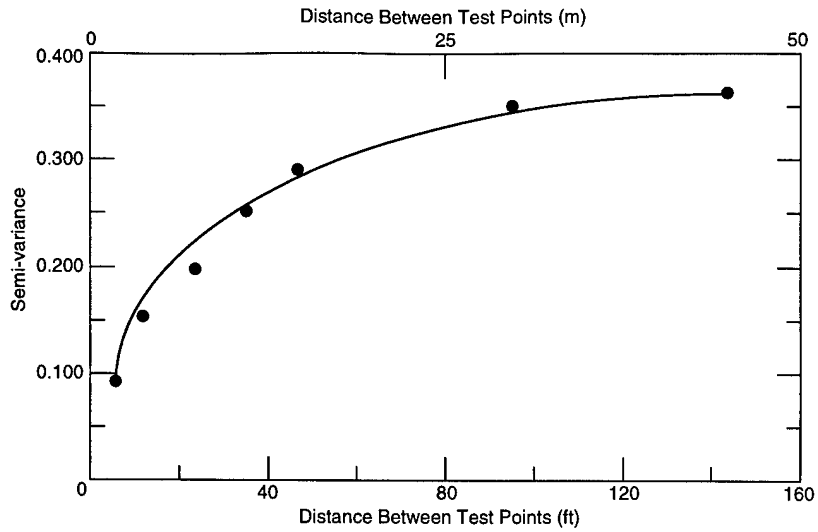


Figure 5. Variogram of normalized FWD center deflections, LV27 subgrade.

test point separations distances will decrease and vice versa. This will reduce testing at unnecessary locations and provide more representative coverage of any pavement section for pavement evaluation and overlay design. Furthermore, this technique will probably minimize lane closure time, thereby improving both employee and public safety.

SUMMARY

Compilation of survey results from an NDT practices questionnaire distributed to state DOTs showed that Dynatest FWDs are by far the most popular nondestructive pavement testing device. The current uses for such FWD/NDT devices are pavement overlay design, pavement evaluation network/inventory, research, void detection, and load transfer determination. Table 1 summarizes software and analytical tools used. AASHTO guidelines and DARWIN, which uses AASHTO methods, provide the most frequently used overlay design technique. In-house programs are also used quite often. DARWIN (and AASHTO), MODULUS, ELMOD, and in-house programs constitute the most commonly used methods for pavement evaluation.

Most states test fewer than 700 lane-miles per year for overlay design and fewer than 1000 lane-miles per year for network level testing. Test point spacing for both overlay design and network/inventory ranges from 100 to 1000 ft, with outliers in both categories reaching 3000 ft.

As a follow-up to compiling and assessing survey results, we hope to minimize the cost for overlay design and pavement evaluation by developing a computer program that optimizes the number and location of FWD test points as data are collected in the field. The program will be based upon a mathematical model that enables quantification of spatial variability (of pavement stiffness). Based upon preliminary work, this continually adjusting optimal test point configuration program would optimize the FWD testing process by eliminating both undertesting and overtesting (thereby eliminating under- or overdesign), minimize lane closure time (thereby improving both employee and public safety), and guarantee that adequate data be collected for pavement evaluation and overlay design.

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Kestler, M.A., M.E. Harr, R.L. Berg, and D.M. Johnson (1994) Spatial variability of falling weight deflectometer data: A geostatistical analysis. In *Proceedings, Bearing Capacity of Roads and Airfields Conference, Minneapolis, Minnesota.*

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APPENDIX A: NONDESTRUCTIVE PAVEMENT TESTING DEVICES

GENERAL INFORMATION

Historically, pavement deflection data have been collected by a variety of equipment that falls into four categories: 1) static beam deflection equipment, 2) automated beam deflection equipment, 3) steady-state dynamic deflection equipment, and 4) impulse deflection equipment (Smith and Lytton 1984).

The following sections provide a brief and simplistic description of the only two categories still used by responding state DOTs, impulse deflection equipment and steady-state dynamic deflection equipment. Although written several years ago, Report No. FHWA/RD83-097 (Smith and Lytton 1984) provides a comprehensive overview of all four categories of NDT equipment and is highly recommended for detailed descriptions.

IMPULSE DEFLECTION DEVICES

Impulse deflection equipment includes any testing device that applies an impulse load to the pavement surface. This is accomplished by lifting and dropping a mass from an adjustable height onto a buffer system that transmits the force through a loading plate to the pavement surface. The impulse load and resulting pavement response closely approximate a moving wheel load and associated pavement deflection. FWDs are impulse deflection devices.

Dynatest falling weight deflectometer

As was discussed in the main text, Dynatest FWDs are by far the NDT device most commonly used by state DOTs. Dynatest pavement testing equipment is mounted on a trailer, and can be towed by a van, truck, or automobile. Drop heights are varied to yield a desired load range. Pavement response is measured by (generally) seven velocity transducers located at desired distances from the center of the load plate. The complete operation, including raising and lowering the load plate and sensors, raising and dropping the mass, recording deflections, and signaling the operator when the system can be moved to the next site, is computer controlled.

KUAB falling weight deflectometer

Conceptually, the KUAB is very similar to the Dynatest FWD: pavement testing equipment is mounted in a towable trailer, an impulse load is applied to the pavement system through a buffer system and steel plate, and complete operation of the device and testing sequence is controlled by a computer housed in the towing vehicle. The primary difference is the addition of a segmented steel plate to more evenly distribute the load on uneven surfaces. Also, deflection is measured by seismic displacement transducers that are differential transformers, and the applied impulse load is longer than that of a Dynatest.

STEADY-STATE DYNAMIC DEFLECTION EQUIPMENT

Steady-state dynamic deflection equipment includes any pavement testing device that applies a dynamic force to produce a sinusoidal vibration in the pavement system. A static load is placed on the pavement surface, then a steady-state sinusoidal vibration is induced with a dynamic-force generator. The magnitude of peak-to-peak force is generally increased during testing. (The static load must also be adjusted accordingly to prevent the device from bouncing off the pavement surface.)

Dynaflect

Chronologically preceding FWDs, the Dynaflect is also trailer mounted and can be towed by any standard vehicle. The Dynaflect was one of the first types of steady-state dynamic deflection devices on the market.

A static load is applied to the pavement surface, then a sinusoidal vibration is applied through an unbalanced fly wheel system. Velocity transducers measure pavement deflection. Testing frequency and pavement response (deflections) are measured simultaneously. Before the introduction of FWDs, the Dynaflect was used for overlay design more than any other automated pavement testing device.

Road Rater

Road Raters can be trailer mounted or incorporated within a vehicle such that towing is unnecessary. Load magnitudes vary for different models.

A load is applied to the pavement through a steel loading plate. The dynamic force is applied by a steel mass accelerated by a servo-controlled hydraulic actuator, and deflections are measured using four (or more) velocity transducers.

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For conversion of SI units to non-SI units of measurement, consult ASTM Standard E380-93, *Standard Practice for Use of the International System of Units,* published by the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103.

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13. ABSTRACT (*Maximum 200 words*)

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